Popular Environmental Sampling Designs

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Sampling designs in common use

These are all probability-based (statistical) and all are well documented in the environmental literature:

- Simple Random
- Systematic/Grid
- Stratified
- Composite
- Incremental
- Rank Set
- Hot spot
- Adaptive Cluster

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Simple Random Sampling

- For this kind of sampling (SRS) every part of the site or population has an equal chance of being in the sample
- A map of the site or a complete list of the population is constructed and every potential sample point identified
- Using a random process (primitive; numbers-from-a-hat, sophisticated; random number generator) select a fixed number of samples to be collected
- Translate the sample points to be collected from the map or list to the physical site

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Simple Random Sampling: Pros

- Simple in concept and provides proper data (theoretical support) for statistical data analysis
- Protects against bias in estimating parameters (e.g., means) and testing hypotheses
- Is the basic building block of more complicated (and efficient) sampling designs

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Simple Random Sampling: Cons

- Ignores available information that could be used to develop more cost-effective sampling designs
- Not as efficient as other designs for delineating patterns of contamination or finding hot spots
- Difficult to find randomly selected sampling locations
- May not be truly representative of the population
- Tends to demand large numbers of samples

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Systematic (Grid) Sampling

- Systematic (grid) sampling consists of collecting samples according to a specified pattern at regular intervals in space or time
- Samples may be collected at the center of each individual grid space or at the nodes of the grid
- The grid is orientated at random across a site or with a random starting point if along a line
- Examples:
  - Square grid patterns over a site
  - equal-interval sampling along a straight line

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Systematic Sampling: Pros

- Easy to explain and implement and provides uniform coverage of site or project
- Good for estimating boundaries, trends or patterns of contamination over space or time.
- May yield more precise estimates of population parameters than other sampling designs
- Required for statistical data analysis to estimate trends and spatial patterns
- Easier than Simple Random to locate samples

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Systematic Sampling: Cons

- Systematic sampling can cause estimated means to be biased if the sampling grid pattern lines up with any pattern of contamination
- More information is needed (than for simple random sampling) about the population to estimate the variance of the estimated mean
- May require a large number of samples if all squares or nodes sampled

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Stratified Sampling

- The target population is divided meaningfully into contiguous sub-populations called strata
- The concept is to divide a relatively high variability population into relatively homogeneous strata
- Sampling locations are selected independently within each stratum using some sampling design (Simple Random, for example)

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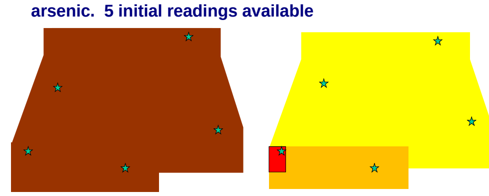
Example: Littlewood Site

- Multi-purpose site is suspected to be contaminated with arsenic. 5 initial readings available



Site before stratification
0.2 – 33.0 ppm
The high variability indicates many samples will be needed for further exploration

Site after stratification
Parking 0.2 – 0.4 ppm
Storage 5.6 ppm
Production 33.0 ppm
More efficient sampling

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Stratified Sampling: Pros

- Dramatically reduces the variability present in the population and hence improves overall precision
- Enables estimates of individual areas to be made and so builds a better conceptual model
- Assists in providing good coverage of the project by not allowing too many samples in the same area
- Allows for increased samples from sensitive or more important areas (Parking vs Storage vs Production)

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Stratified Sampling: Cons

- Requires advance knowledge in order to divide the study area into roughly homogeneous strata before sampling
- The number of samples to be taken in each stratum must be determined (Simple Random or other?)
- If strata boundaries inaccurate, what appears to be outlier data can be due to being incorrectly identified to stratum wrong one) and adversely influence conclusions (Parking vs Storage vs Production)

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Composite Sampling

- Many individual (grab) samples are combined and thoroughly mixed to make a homogeneous whole
- At random, subsamples (composite samples) are made and sent to the laboratory for analysis
- The physical size of composite samples are the same size as those obtained at random

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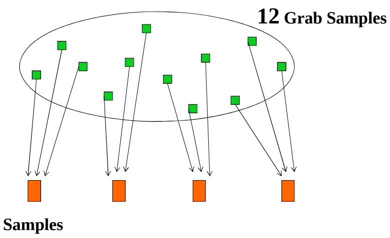
Composite Sampling



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Composite Sampling: Pros

- Allows for estimating the mean contamination with the same precision at a lower cost
- Provides better coverage of the study site without increasing the number of chemical analyses
- Allows for a more representative sample from a basic area of sample support (sampling unit)
- Can be used in combination with other sampling designs

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Composite Sampling: Cons

- Information on individual samples used to form composite samples is lost in compositing
- Potential for loss of contaminants (volatiles) during the mixing and handling phase
- Potential for reactions and interactions among analytes during compositing
- Need to make decision on how many grab samples to be composited and how many composite samples to send for analysis

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Incremental Sampling Design

- Similar to composite sampling but covers a defined decision unit
- After deciding on the mass (volume) to be sent for analysis (e.g. 1500 grams), a large number of smaller, incremental, samples are selected (e.g. 30 increments of 50 grams each)
- Necessary to define the QA protocol and technique for taking each increment to prevent bias

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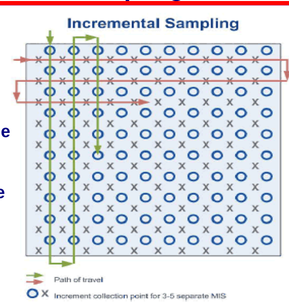
Incremental Sampling

The red path shows the collection of the first incremental sample.

The green path shows the second incremental sample (replicate).

A third incremental sample could be a diagonal path.

Each of these incremental Samples consists of 100 increments



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Incremental Sampling: Pros

- Provides better coverage of the decision area (unit) without increasing the number of chemical analyses
- Allows for a more representative sample from a basic area of sample support (sampling unit)
- Highly effective when large variability in results suspected (e.g. minor hotspots)
- Estimates from incremental sampling very stable

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Incremental Sampling: Cons

- No understanding of spatial variability is gained
- Only valid for estimating the mean
- Decision on how many increments to take is arbitrary
- Potential for loss of contaminants (volatiles) during the mixing and handling phase
- Comparison of incremental samples to other samples is difficult
- Size / shape of decision unit not adjustable after sample collection

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Ranked Set Sampling

- A sampling design where expert judgment is used in combination with simple random sampling
- Decide on how many samples are needed (m)
- Using SRS, create m x m (m-squared) potential samples (note potential samples identified, but not collected)
- From each set of n potential samples, the expert then ranks these potential samples according to some criterion
- One sample is then selected from each set of potential samples to send for analysis

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Statistician & Expert

- Statistician:
  - Selects "m" sets of random samples of size "m" as potential samples (total "m x m") using SRS
- Expert:
  - Within each set, the expert ranks (grades) the potential samples from highest to lowest based on the expert's opinion or some criterion
- Together:
  - From the first set, the largest is chosen; from the second set, the second largest is chosen; from the third set, the third largest is chosen etc
- Result:
  - A random sample of size "m" with special properties

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Ranked Set Sampling: pros

- Increased chance of good representativeness through the incorporation of expert advice
- Better precision than Simple Random Sampling that can be most impressive depending on data distribution
- Same simple formulae to use, no special adjustments
- Mistakes in ranking still leaves the resulting sample better than SRS
- Even if the expert advice is useless the resulting sample is as good as SRS

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Ranked Set Sampling: cons

- Need to find some variable to do the ranking on
- Possible increased costs of having to pay the expert
- Difficulty quantifying the exact amount of improvement the resulting "super sample" is over SRS

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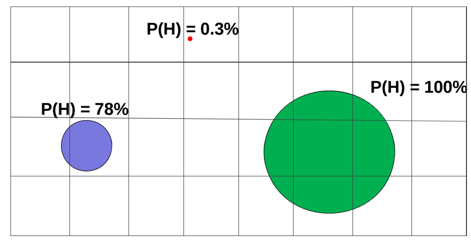
Hot-Spot Sampling

- Detecting the presence of a potential "hot-spot" by covering the site with a grid of known size and mesh-spacing, then taking samples at the nodes of the grid
- Define the area, volume, and shape of the hot spot
- Should estimate the concentration of the potential hot-spot
- Need to decide the risk of missing a hot-spot

Hot-Spot Size and Grid Spacing



Hot-Spot Sampling: Pros

- Very effective in finding hot spots of a specified size and shape
- Able to control the probability of missing a hot-spot of a given size
- Indirectly delineates the size and shape of the hot-spot

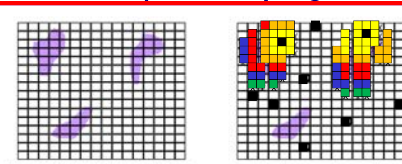
Hot Spot Sampling: Cons

- Need to specify the size and shape the potential hot-spot and this could be difficult
- Need to decide the acceptable chance of missing a hot-spot of a certain size – should be related to risk
- Potentially expensive due to need to take samples from all over the site
- Need the capacity to conduct multiple rounds of sampling

Adaptive Sampling

- Select an initial probability based sample, evaluate the results, then choose additional samples based on results from the initial sample
- The additional samples are taken all around the initial samples having an elevated level of interest (e.g., high contamination level)
- Repeat additional sampling until further samples show nothing of interest (e.g., lower level of contamination)

Adaptive Sampling



Areas with elevated concentrations — Adaptive sampling results

The purple areas represent unknown contamination

Black	*Initial sample (there were 3 hits)*
Yellow	*1^{st} round (there were 6 hits)*
Orange	*2^{nd} round (there were 6 hits)*
Red	*3^{rd} round (there were 8 hits)*
Blue	*4^{th} round (there were 2 hits)*
Green	*5^{th} round (there were no hits)*

Adaptive Sampling: Pros

- A clear advantage in delineating and investigating the size of potential hot-spots
- Allows for the ability to estimate the population mean and variance using all the available data
- Research shows that the variance of the population mean estimate can be considerably smaller than that for simple random sampling leads to better accuracy of results

Adaptive Sampling: Cons

- Complicated computation of statistics such as mean and variance for use in making probabilistic statements
- Time-consuming: iterative sampling required until no more samples of interest are found
- Sample sizes usually much larger than traditional designs causing greater cost

Sampling Designs: Conclusions

- Probabilistic more defensible than judgmental
- If only relatively few samples can be afforded, then more sophisticated designs will be needed
- The more sophisticated the design, the more sophisticated the analysis
- Advice: *Guidance on Choosing a Sampling Design for Environmental Data Collection (G-5S)* download from: www.epa.gov/quality/qa_docs.html